Chapter 10

Model Validation and Uncertainty Analysis

CONTENTS: The results obtained from the models used in this study were compared with limited direct and indirect ^{131}I data available from the time of the tests in order to compare the findings and to provide an estimate of the uncertainty attached to the doses that have been calculated. A simplified uncertainty analysis is also carried out on the basis of the assumed uncertainties attached to the parameter values.

Given the large number of data that are required to estimate thyroid doses in this study, as well as the very large number of results which are presented in the Annexes and Subannexes, it is important to evaluate the reliability of the thyroid doses that are estimated as well as the uncertainties that are associated with these estimates. This chapter addresses these issues and is divided into three parts: (a) model verification, showing the extent to which results calculated with the computer programs agree with results hand-calculated using the equations and the parameter values; (b) model validation, in which the limited available measured ^{131}I concentrations in man, in animals, and in the environment are compared with the results obtained with the models; and (c) uncertainty analysis, in which the uncertainties associated with the dose estimates are evaluated from the assumed uncertainties attached to the parameter values.

10.1. MODEL VERIFICATION

Model verification was carried out at various levels:

- Using hand-calculators, the computer programmers verified the exposure and dose estimates obtained for several counties and carefully examined the estimates for all counties that were plotted on maps in order to detect obvious errors.

- Numerous drafts of the report were discussed and reviewed in whole or in part during meetings of the Task Group on Exposures, at which time experts were able to evaluate the database, methodologies, analyses and exposure estimates.

- Various drafts of the report were presented and discussed at meetings of the Advisory Committee, one member of which reviewed the computer files and prepared independent computer programs in order to verify the results obtained for a large number of counties. Reviewers also carefully verified some of the estimates.

10.2. MODEL VALIDATION

Few measurements of ^{131}I in the environment and in man were made in the 1950s; however, those that are available in the literature were compared with the results obtained in this assessment. Because the thyroid dose received by man is of particular interest, greater importance is given to the measurements in man than to the measurements in the environment.

10.2.1. Measurements in Man

10.2.1.1. Urine

During the weapons test series Teapot in 1955, human urine specimens from 17 United States military posts were analyzed for ^{131}I activity by the Walter Reed Army Institute of Research. These facilities were located across the U.S. in Arizona, California, Colorado, the District of Columbia, Florida, Illinois, Massachusetts, Michigan, Nevada, Ohio, Oklahoma, South Carolina, Texas, Utah, and Washington. Twenty-four-hour urine collections were obtained at weekly intervals from the end of January to the end of May of 1955 from 10 healthy adult males selected at each of these military facilities (Hartgering et al. 1955; Schrodt et al. 1956).

Several assumptions have been used to relate the measured urine concentrations to the predicted time-integrated concentrations in milk:

- The ^{131}I urine concentrations measured in the 24-hour urine samples were taken to represent averages over the weekly collection intervals. This is a very crude assumption since urinary values fluctuate widely, as they reflect exposures within the same 24-hour period and are very sensitive to both the amount of milk consumed and the ^{131}I concentration in that milk. Because of these fluctuations, it seemed reasonable to compare only the observed and predicted time-integrated concentrations of ^{131}I in urine for the entire Teapot series.

- The milk consumed on military posts had the same average concentration as the rest of the milk consumed in the county in which the station was located.

- The milk consumption rate is 0.26 L d^{-1} (average value for adult males given in *Table 5.9* of **Chapter 5**).

- The fraction of ^{131}I intake that finds its way into urine is 0.8 (see **Appendix 6, Section A6.1.1**).

Detailed information on the measurements of ^{131}I in urine is provided by Hartgering et al. (1955) for 15 of the 17 United States military posts. The comparison of the observed and the measured activities in urine for those 15 United States military posts is presented in *Table 10.1*. With one exception, the predicted activities, P, are greater than the observed activities, O. The P/O ratios range from 0.9 to 60, with a geometric mean of about 10; this is considered to be a reasonably good agreement, especially in view of the fact that no information is available on the type, amount, or origin of milk consumed by the service personnel at those military facilities.

Table 10.1. Comparison of predicted and observed activities of ^{131}I in urine from the Teapot series.

Site	Activity in urine (nCi)		Predicted/Observed (P/O) ratio
	observed	predicted	
Ogden, UT	5.9	31	5.3
Camp Mercury, NV	4.3	34	7.9
Belleville, IL	3.3	29	8.8
Denver, CO	3.0	46	15
Oklahoma City, OK	2.3	74	32
Phoenix, AZ	1.5	1.3	0.9
Mount Clemens, MI	1.1	9.1	8.3
Greenville, SC	0.88	53	60
Washington, D.C.	0.88	23	26
Columbus, OH	0.84	36	43
San Antonio, TX	0.71	22	31
Riverside, CA	0.62	0.98	1.6
Spokane, WA	0.57	9.6	17
Chicopee Falls, MA	0.53	5.0	9.4
San Francisco, CA	0.49	4.8	9.8

10.2.1.2. Thyroid

Several series of measurements of ^{131}I in human thyroids were made in 1955 and 1957:

- Van Middlesworth (1956) measured the ^{131}I content of human thyroids collected in hospitals of Memphis, Tennessee, during the spring of 1955. The highest concentration (0.1 nCi g^{-1}) observed was after the Zucchini test of May 1955. If a mean residence time of 10 days is assumed for ^{131}I in the thyroid, a time-integrated concentration of 1 nCi d g^{-1} is derived from the observed concentration. The predicted time-integrated concentration of ^{131}I in milk in Memphis was 29 nCi d L^{-1}. If it is assumed that there is: (1) a milk consumption rate of 0.3 L d^{-1}; (2) a fractional uptake by the thyroid of 0.24; (3) a mean time of residence in the thyroid of 10 days; and (4) a thyroid mass of 18 g, the predicted time-integrated concentration in the thyroid is 1.2 nCi d g^{-1}. The predicted-to-observed ratio is 1.2.

- Also in 1955, Comar et al. (1957) analyzed the ^{131}I content of human thyroids from autopsies from various locations in the United States. Unfortunately, results are reported for large areas, so that it is not possible to estimate the corresponding time-integrated concentration of ^{131}I in milk with reasonable accuracy.

- In 1957, human thyroids from autopsies from the San Francisco area were measured for their ^{131}I concentrations by White and Jones (1956). The average concentration during the period from May 20 to July 31 was 1.4 pCi g^{-1}, resulting in a time-integrated concentration of 0.10 nCi d g^{-1} in the thyroid. The predicted time-integrated concentration in milk in the San Francisco area resulting from the six tests conducted at the NTS from May 20 to July 31 was 3.3 nCi d L^{-1}, corresponding to 0.13 nCi d g^{-1} in the thyroid. The predicted-to-observed ratio is equal to 1.3.

10.2.2. Measurements in Cattle Thyroids

Measurements in cattle thyroids were made by the same investigators who analyzed human thyroids:

- Van Middlesworth (1956) collected cattle thyroids from slaughterhouses within 200 miles of Memphis, Tennessee. For the test Zucchini of May 1955, an exposure of 4-6 rep was derived from the measurements. Using a relationship of 0.0123 rep per nCi d g^{-1}, as recommended by Dunning (1956), the "observed" time-integrated concentration in the cattle thyroids is 300-500 nCi d g^{-1}.

  The predicted average time-integrated concentration of ^{131}I in milk following Zucchini over a 200-mile circle centered in Memphis, Tennessee, is about 30 nCi d L^{-1}. Using a ratio between cattle thyroids and milk concentration of 3 nCi g^{-1}/nCi L^{-1}, as recommended by Soldat (1963), the predicted time-integrated concentration in cattle thyroids is 90 nCi d g^{-1}. The predicted-to-observed ratio is in the 0.2 to 0.3 range.

- The ^{131}I concentrations measured in cattle thyroids in 1955 by Comar et al. (1957) have not been compared to predicted concentrations because of the imprecise origin of the samples.

- Thyroids from cattle slaughtered in the San Francisco Bay area from February until September, 1955, were collected by White and Dobson (1956). Measured concentrations of ^{131}I in the thyroids corresponded to a maximum time-integrated concentration of 95 nCi d g^{-1} in the cattle thyroids. The predicted time-integrated concentration of ^{131}I in milk in the San Francisco Bay area is 20 nCi d L^{-1} for the Teapot series. This corresponds to a time-integrated concentration in cattle thyroids of 60 nCi d g^{-1}. The predicted-to-observed ratio is 0.6.

- The average thyroid concentration of ^{131}I in range-fed cattle in the San Francisco area over the period from May 20 to July 31, 1957, was 0.63 nCi g^{-1} (White and Jones, 1956). The observed time-integrated concentration in the thyroid is therefore 45 nCi d g^{-1}. The predicted time-integrated concentration in milk is 3.3 nCi d L^{-1}, or 9.9 nCi d g^{-1} in the thyroid. The predicted-to-observed ratio is 0.2.

10.2.3. Measurements in Milk

Measurements of the ^{131}I concentration in milk were carried out in five milksheds by the Public Health Service in 1957 (Campbell et al. 1959). One-gallon samples were collected once a month. Unfortunately, the date of collection was not reported, rendering the measured concentrations of little use. More complete information is available beginning in 1962 but global tests contributed much more to the ^{131}I concentrations in milk at that time than did the tests at NTS.

10.2.4. Discussion

The infrequent measurements of ^{131}I in the environment and in man that were carried out in the 1950s and reported in the literature point to a relatively good agreeement with the concentrations predicted with the model. The comparison of the predicted concentrations in urine and of the measured values in 15 U.S. military posts in 1955 seems to indicate that the concentrations in urine are overpredicted by a factor of about 10. A better agreement is obtained with the measurements of ^{131}I in human or in cattle thyroids. It should be pointed out, however, that the comparison between measured and predicted values necessitated the use of several assumptions, and that there is no guarantee that the samples measured were representative of county averages. As already indicated, large variabilities are attached to individual doses, mainly as a result of individual dietary habits and metabolisms of iodine. However, to the extent that comparisons can be made, it would seem that the most relevant one would be to compare the predicted values of ^{131}I in the thyroid with those very few human thyroids in which ^{131}I actually was measured. This comparison shows unexpectedly good agreement, however limited the usefulness of the comparison in a more general sense.

10.3. UNCERTAINTY ANALYSIS

10.3.1. Introduction

Uncertainties are associated with the average dose estimates obtained for each test and each county (see **Chapters 6** and **7**); these uncertainties were estimated for the:

(a) per capita thyroid doses over the entire population,

(b) average thyroid doses over the population of milk drinkers in each age and sex group,

(c) average thyroid doses for the high-exposure group in each age and sex group,

(d) average thyroid doses for the low-exposure group in each age and sex group,

(e) average thyroid doses for the group consuming milk from backyard cows in each age and sex group,

(f) average thyroid doses for the infants consuming mother's milk, and

(g) for the collective doses over the entire population of each county and of the entire U.S. for each test.

The parameters and assumptions used in the dose assessment have been discussed in detail in **Chapters 3** through **7**. In carrying out the uncertainty analysis, two guiding principles have been observed:

- That all major sources of uncertainty are taken into account (either implicitly or explicitly).
- That the analysis is no more complex than is deemed to be necessary.

The method selected for the uncertainty analysis is the multiplicative log-normal approach, which is a simple analytical method that does not require many computer resources and the results of which can be verified with a hand-held calculator with power, exponential, and logarithmic functions. This method, however, relies on two critical assumptions:

- All the parameter values must be assumed to be log-normally distributed, regardless of what data or expert opinion may suggest.
- The distribution of the sum of log-normally distributed parameters must be assumed to be log-normal.

Further discussion of the multiplicative log-normal approach can be found in **Chapter 3**.

10.3.2. Results

A very large number of parameters are involved in the dose calculations. For the purposes of the uncertainty analysis, some of those parameters have been combined in order to simplify the equations.The uncertainties attached to all the parameters have been assigned as realistically as possible, given the constraint that all distributions need to be assumed to be log-normal.

Detailed results are tabulated in the Annexes and Subannexes for each test and each county of the contiguous United States. The best estimates of each of the quantities presented in the tables (e.g., deposition of ^{131}I on the ground, time-integrated concentrations of ^{131}I in a certain category of milk, or average thyroid dose to a particular population group) are meant to represent the geometric means, GM, or medians, of the distributions (which means that 50% of the values are expected to be higher than the best estimate found in the table for a given quantity, and that 50% of the values are expected to be lower than the best estimate).

The uncertainties are expressed in terms of geometric standard deviations, GSD, implying that 67% of the values in the distribution associated with a best estimate, GM, are expected to lie between GM / GSD and GM x GSD, while 97% are expected to range from GM/(GSD)^2 and GM x (GSD)^2. For example, if an average thyroid dose to a particular population group from a given test is listed with a best estimate, GM, of 0.4 rad and with an associated uncertainty, GSD, of 2.5, this means:

(a) That there is a 50% probability that the true value of the average thyroid dose is greater than 0.4 rad, and, conversely, that there is a 50% probability that the average thyroid dose is lower than 0.4 rad;

and,

(b) that the distribution of the expected values is such that there is a 67% probability that the true value of the average thyroid dose lies between:

$$GM / GSD = 0.4 / 2.5 = 0.16 \text{ rad, and}$$

$$GM \times GSD = 0.4 \times 2.5 = 1 \text{ rad,}$$

and that there is a 97% probability that the true value of the average thyroid dose lies between:

$$GM / (GSD)^2 = 0.4 / 6.25 = 0.06 \text{ rad, and}$$

$$GM \times (GSD)^2 = 0.4 \times 6.25 = 2.5 \text{ rad.}$$

The estimates provided in the Annexes and in the Sub-annexes for the average doses to the various population groups show that the associated GSDs range, in general, between 2 and 10, the lowest GSDs being usually related to populations living in the vicinity in the NTS in areas for which County Data Base or Town Data Base data were available. The highest GSDs are associated with the dose estimates for which the depositions of ^{131}I were assessed with the meteorological approach.

10.4. SUMMARY

- Model verification was carried out by the researchers involved in the preparation and discussion of the report using spot check calculations; a set of separate computer programs also was prepared in order to verify the models on a more extensive scale.

- Model validation was effected by comparing the infrequent measured results of ^{131}I in the environment and in man that were carried out in the 1950s and reported in the literature with the results calculated with the models. Although concentrations in man are usually overpredicted, a relatively good agreeement was obtained between measured and calculated results.

- The uncertainties associated with the estimates provided for the average doses to the various population groups are expressed in terms of geometric standard deviations, GSD, which are assessed to range, in general, between 2 and 10, the lowest GSDs being usually related to populations living in the vicinity in the NTS in areas for which County Data Base or Town Data Base data were available. The highest GSDs are associated with the dose estimates for which the depositions of ^{131}I were assessed with the meteorological approach.

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